JC14 Rec'd PCT/PTO 27 MAR 2001

SUBSTITUTE FORM PTO-1390 U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

ATTORNEY'S DOCKET NUMBER
12816-008001

U.S. APPLICATION NO. (If Known, see 37 CFR 1.5) 09/806140

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/DE99/02752	1 September 1999	28 September 1998

TITLE OF INVENTION
DIGITAL RECEIVER FOR A SIGNAL PRODUCED

APPLICANT(S) FOR DO/EO/US
Heinrich Schenk

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to promptly begin national examination procedures (35 U.S.C. 371(f)).
4. ☒ The US has been elected by the expiration of 19 months from the priority date (PCT Article 31).
5. ☒ A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   a. ☒ is attached hereto (required only if not communicated by the International Bureau).
   b. ☐ has been communicated by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☒ An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
   a. ☒ are attached hereto (required only if not communicated by the International Bureau).
   b. ☐ have been communicated by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☐ have not been made and will not be made.
8. ☐ An English language translation of amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. ☐ An English language translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11 to 16 below concern other documents or information included:

11. ☐ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☒ A FIRST preliminary amendment.
    ☐ A SECOND or SUBSEQUENT preliminary amendment.
14. ☒ A substitute specification.
15. ☐ A change of power of attorney and/or address letter.
16. ☐ Other items or information:
    ☐
    ☐
    ☐
    ☐
    ☐

CERTIFICATE OF MAILING BY EXPRESS MAIL Express Mail Label No. EL258935033US

I hereby certify under 37 CFR §1.10 that this correspondence is being deposited with the United States Postal Service as Express Mail Post Office to Addressee with sufficient postage on the date indicated below and is addressed to the Commissioner for Patents, Washington, D.C. 20231.

3-27-2001	Samantha Bell	Samantha Bell
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U.S. APPLICATION NO. (IF KNOWN) 09/806140	INTERNATIONAL APPLICATION NO. PCT/DE99/02752	ATTORNEY'S DOCKET NUMBER 12816-008001

17. ☒ The following fees are submitted:

	CALCULATIONS	PTO USE ONLY
Basic National Fee (37 CFR 1.492(a)(1)- (5)): Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO .... **$1000** International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO .... **$860** International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO .... **$710** International preliminary examination fee paid to USPTO (37 CFR 1.482) but all claims did not satisfy provisions of PCT Article 33(1)-(4) .... **$690** International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(1)-(4) **$100**		
ENTER APPROPRIATE BASIC FEE AMOUNT =	$860.00	
Surcharge of **$130** for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(e)).	$0.00	

Claims	Number Filed	Number Extra	Rate		
Total Claims	7 - 20 =	0	x **$18**	$0.00	
Independent Claims	1 - 3 =	0	x **$80**	$0.00	
MULTIPLE DEPENDENT CLAIMS(S) (if applicable)			+ **$270**	$0.00	

TOTAL OF ABOVE CALCULATIONS =	$860.00	
☐ Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by 1/2.	$0.00	
SUBTOTAL =	$860.00	
Processing fee of **$130** for furnishing the English Translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492(f))	$0.00	
TOTAL NATIONAL FEE =	$860.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31).**$40.00** per property +	$0.00	
TOTAL FEES ENCLOSED =	$860.00	
	Amount to be refunded:	$
	Charged:	$

a. ☒ A check in the amount of $860.00 to cover the above fees is enclosed.
b. ☐ Please charge my Deposit Account No. 06-1050 in the amount of $0.00 to cover the above fees. A duplicate copy of this sheet is enclosed.
c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 06-1050. A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b) must be filed and granted to restore the application to pending status.

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REGISTRATION NUMBER: 41,942

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09/806140

Attorney's Docket No.: 12816-008001 / S0751 SB/fis

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant	: Heinrich Schenk	Art Unit	: Not yet assigned
Serial No.	: Unassigned	Examiner	: Not yet assigned
Filed	: Herewith		
Title	: DIGITAL RECEIVER FOR A SIGNAL PRODUCED USING DISCRETE MULTITONE MODULATION		

Box PCT
Commissioner for Patents
Washington, D.C. 20231

PRELIMINARY AMENDMENT

Prior to examination, please amend the application as follows:

In the specification:

Please replace the specification as filed with the attached substitute specification.

In the claims:

Please amend claims 1-7 as shown in the attached claims.

In the abstract:

Please insert the attached abstract.

10/ 40 "10421050850 (vertical stamp in left margin)

REMARKS

Applicant amends the claims to remove multiple dependencies and to more particularly and distinctly claim the subject matter of the invention. Applicant encloses a copy of the claims as pending, together with a copy showing differences between the claims as filed and the claims now pending.

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March 27, 2001
Date of Deposit

Samantha Bell
Signature

Samantha Bell
Typed or Printed Name of Person Signing Certificate

Pursuant to Rule 1.121(b)(3), Applicant requests that the attached substitute specification replace the originally filed specification. The attached substitute specification corrects minor typographical errors and adds section headers to facilitate examination of this application. In addition, references to elements in the drawings have been typeset in bold to enable the Examiner to more easily locate references to those elements in the specification. No new matter is introduced in this substitute specification. Applicant includes another version of the substitute specification marked to show revisions.

Applicant requests that the attached abstract replace that published in the PCT publication.

No additional fees are believed to be due in connection with the filing of this amendment. However, if additional fees are due, of if credits are forthcoming, please adjust our Deposit Account No. 06-1050.

Respectfully submitted,

Date: March 27, 2001

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PCT/DE99/02752

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Description

Digital receiver for a signal produced using discrete multitone modulation

The invention relates to a digital receiver for a signal produced using discrete multitone modulation, as claimed in the precharacterizing clause of patent claim 1.

Discrete multitone modulation (DMT) - also referred to as multicarrier modulation - is a modulation method which is particularly suitable for transmitting data via channels in which linear distortion occurs. In comparison to so-called single-carrier methods such as amplitude modulation, which has only one carrier frequency, discrete multitone modulation makes use of a large number of carrier frequencies. The amplitude and phase of each individual carrier frequency is modulated using quadrature amplitude modulation (QAM). This thus results in a large number of QAM-modulated signals. A specific number of bits may in each case be transmitted per carrier frequency. Discrete multitone modulation is used for digital audio broadcast DAB where it is referred to as OFDM (Orthogonal Frequency Division Multiplex) and for transmitting data via telephone lines, where it is referred to as ADSL (Asymmetric Digital Subscriber Line).

In ADSL, a DMT-modulated signal is used to transmit data from a switching center via a subscriber line to a subscriber with an analog connection. In this case, ETSI and ANSI Standards state that each carrier frequency has a bandwidth of approximately 4 kHz, and that at most up to 15 bits per second per Hz are transported. The actual number of bits per second per Hz may differ for each carrier frequency, thus allowing the data rate and transmission spectrum to be matched to the transmission channel.

A DMT transmission system has a coder which combines the bits in a serial digital data signal which is intended to be transmitted, to form blocks. A specific number of bits in a block in each case have an associated complex number. A complex number is used to represent a carrier frequency $f_i = i/T$ where $i = 1, 2, \ldots, N/2$ in the discrete multitone modulation, with all the carrier frequencies f_i being distributed at equal intervals. T is the time duration of a block. Inverse Fourier transformation is used to transform the carrier frequencies represented by the complex numbers to the time domain, where they directly represent N samples of a DMT signal to be transmitted. In order to allow Inverse Fast Fourier Transformation (IFFT) to be used, a power of two is selected for N. This reduces the complexity for Inverse Fast Fourier Transformation.

After the Inverse Fast Fourier Transformation, a cyclic prefix is carried out, with the last M ($M < N$) of the samples being attached once again to the start of a block. A periodic signal is thus simulated for a receiver, once the transient process produced by a transmission channel has decayed after M samples corresponding to a time $T \cdot M/N$. The equalization complexity in the receiver can be greatly reduced by means of the cyclic prefix since, after demodulation in the receiver, all that is necessary is multiplication by the inverse of the transfer function of the transmission channel in order to compensate for the linear distortion in the transmission channel. This requires one complex or four real multiplications for each carrier frequency.

In ADSL, the physical transmission channel is a two-wire line (twin-core copper cable) in the telephone network. The two-wire line requires a long time for the transient process in comparison to the length of a block. On the other hand, any additional transmission capacity required as a result of the cyclic prefix is intended to be as low as possible.

A cyclic prefix of M = 32 is defined in ADSL for a block length of N = 512. However, the transient process on the two-wire line has not yet decayed after M = 32 values. Additional errors thus occur in the receiver, which cannot be compensated for by a frequency-domain equalizer.

Such additional errors can be reduced by using special signal processing measures in the receiver.

To this end, a time domain equalizer (TDEQ) is connected upstream of a demodulator. The time domain equalizer is in the form of a digital transversal filter, whose coefficients are adjustable. The object of the time domain equalizer is to shorten the transient process of the transmission channel. The design of such time-domain equalizers is described in Al-Dhahir, N., Cioffi, J.M., "Optimum Finite-Length Equalization for Multicarrier Transceivers", IEEE Trans.on Comm., Vol. 44, No. 1, Jan 1996. However, this has the disadvantage that the digital transversal filter used as the time-domain equalizer has a large number of coefficients, and the adaptation of the digital transversal filter is complex. A filter length of 20 to 40 coefficients means that approximately 50 to 100 million multiplication operations must be carried out per second. In addition, each coefficient must be adjusted for adaptation of the digital transversal filter.

The technical problem on which the invention is based is thus to specify a digital receiver for a signal produced using discrete multitone modulation, which receiver has a time-domain equalizer which can be adapted more quickly and which carries our fewer multiplications per second.

This problem is solved by a digital receiver for a signal produced using discrete multitone modulation and having the features of patent claim 1. Advantageous refinements can be found in the respective dependent claims.

The invention relates to a digital receiver for a signal produced using discrete multitone modulation. The digital receiver has an analog/digital converter to which the signal produced using discrete multitone modulation is supplied, and has a time-domain equalizer connected downstream from the analog/digital converter. The time-domain equalizer in turn has a digital filter with fixed coefficients. The fixed coefficients of the digital filter as are required for adaptive digital filters and which require no effort for adaptation are advantageous in this case.

In one particularly preferred embodiment, the digital filter has integer values as fixed coefficients. It is particularly advantageous in this case that operations with integer values are less complex than operations with sliding-point values.

In a further particularly preferred embodiment, the digital filter has values which can be represented by shift operations as fixed coefficients. This advantageously allows multiplication operations to be replaced by shift operations, which are less complex.

In one preferred embodiment, the digital filter has a zero at 0 Hz, thus advantageously shortening the impulse response of the transmission system.

In a further preferred embodiment, the digital filter has a high-pass transfer function.

In one particularly preferred embodiment, the digital filter has a series circuit comprising a large number of first-order digital filters. The first-order filters can advantageously be produced very easily.

In a further particularly preferred embodiment, each first-order digital filter has a state memory, a shift register, a digital subtraction circuit and a digital addition circuit. The simple construction of each first-order filter is advantageous in this case, with no complex multiplication stages being required.

Further advantages, features and application options of the invention will become evident from the

following description of exemplary embodiments in conjunction with the drawing, in which:

Figure 1 shows a transmission path with a digital receiver for a signal produced using discrete multitone modulation; and

Figure 2 shows an exemplary embodiment of a time-domain equalizer according to the invention; and

Figure 3 shows a diagram illustrating the effect of a time-domain equalizer according to the invention.

In the transmission path illustrated in Figure 1 and having a digital receiver 12, a DMT transmitter 11 produces a signal modulated using discrete multitone modulation. The signal in this case has N/2 carrier frequencies f_1, which are produced by discrete multitone modulation. Each carrier frequency is in this case amplitude-modulated and phase-modulated using quadrature amplitude modulation. In the DMT transmitter 11, the signal is provided with a cyclic prefix comprising M samples, and is converted by digital/analog conversion to an analog signal for transmission. The DMT transmitter 11 transmits the signal via a transmission channel 1 to the digital receiver 12.

The transmission channel 1 is a channel which produces linear distortion. In the case of ADSL transmission paths, the transmission channel is a two-wire line. Such linear distortion produced by the transmission channel 1 is compensated for once again in the digital receiver 12 by means of equalizers which operate in the frequency domain.

In the digital receiver 12, the signal is supplied to an analog/digital converter 2, which converts it to a sequence of digital values u_k.

The sequence of digital values u_k is supplied to a time-domain equalizer 3. The time-domain equalizer 3 is used to shorten the stabilization time of the DMT transmitter 11, of the transmission channel 1 and of the time-domain equalizer 3 itself. If the stabilization time is greater than the cyclic prefix time duration, errors occur in the decision-maker circuits 70 to 7n in the digital receiver 12. The time-domain equalizer 3 is intended to shorten the stabilization time without needing to produce any zeros in the frequency band which is used for transmission. To this end, the time-domain equalizer 3 has a digital filter with fixed coefficients and having the following transfer function ($z = u_k$):

$$H(z)=\prod_{v=1}^{n}\left(\frac{1-z^{-1}}{1-c_v\cdot z^{-1}}\right) \text{ where } c_v = \pm(1-2^{-L}) \qquad (1)$$

This is the transfer function of a multistage digital filter which has fixed coefficients c_v and is produced by a series circuit comprising n second first-order digital filters with a transfer function

$$H_v(z)=\frac{1-z^{-1}}{1-c_v\cdot z^{-1}} \text{ where } c_v = \pm(1-2^{-L}). \qquad (2)$$

The transfer function H(z) of the time-domain equalizer 3 has a zero at 0 Hz, and is thus the transfer function of a high-pass filter. This is the most effective way to shorten the stabilization process of the transmission channel.

The digital values produced by the time-domain equalizer 3 are supplied to a serial/parallel converter 4 which removes the cyclic preface and produces blocks

which are supplied to a discrete Fast Fourier Transformation device 5.

The discrete Fast Fourier Transformation device 5 converts the signals represented by the blocks from the time domain to the frequency domain. Each converted block at the output of the discrete Fast Fourier Transformation device 5 has N/2 complex numbers. Each complex number represents a carrier frequency $f_1 = i/T$ where $i = 1, 2, \ldots, N/2$ for the discrete multitone modulation, with all the carrier frequencies f_1 being distributed at equal intervals. T is the time duration of a block.

The discrete Fast Fourier Transformation device 5 is followed by a frequency-domain equalizer 60, ..., 6m for each carrier frequency $f_1, \ldots, f_{N/2}$ and this carries out the equalization process in the frequency domain. To this end, each complex number in the conversion block which represents one carrier frequency is multiplied by the inverse transfer function of the transmission channel 1. This requires one complex multiplication operation, or four real multiplication operations.

Each frequency-domain equalizer 60, ..., 6m is followed by a respective decision-making circuit 70, ..., 7m, which produces a multistage value from the output signal from the frequency-domain equalizer 60, ..., 6m.

Each decision-making circuit 70, ..., 7m is in each case followed by a decoder circuit 80, ..., 8m, which produces a digital value from the multistage value.

The output signals from the decoder circuits 80, ..., 8m are supplied in parallel to a parallel/serial converter 9, which is connected to a data sink 10. The parallel/serial converter 9 supplies the data sink 10 with a serial stream of digital data, corresponding to the digital data from the DMT transmitter 11.

Figure 2 shows an exemplary embodiment of a time-domain equalizer according to the invention.

The time-domain equalizer has a series circuit comprising n second first-order digital filters with a transmission function as in Equation (2). Figure 2 shows only two first-order digital filters 100 and 200. Further second first-order digital filters are indicated by dots.

All the second first-order digital filters 100 and 200 are constructed in the same way. A discrete input value sequence is supplied to a first inverting input of a digital subtraction circuit 101 or 201, respectively, and, in parallel, to a first non-inverting input of a digital addition circuit 103 or 203, respectively. One output of the digital addition circuit 103 or 203, respectively, is an output of the second first-order digital filter and is fed back in parallel form to a non-inverting input of the digital subtraction circuit and, via a shift register, to a second inverting input of the digital subtraction circuit 101 or 201, respectively. The shift register 104 or 204, respectively, multiplies a discrete output value by shifting to the right, bit-by-bit. In consequence, the discrete output value is multiplied by an integer number 2^{-L}. One output of the digital subtraction circuit 101 or 201, respectively, is passed via a state memory 102 or 202, respectively, to a second non-inverting input of the digital addition circuit 103 or 203, respectively. The state memory 102 or 202, respectively, produces a delay by one clock period of the clock which is used to clock the discrete input sequence.

If L = 0 is chosen, the second digital filters 100 and 200 are non-recursive. In this case, in accordance with Equation (2), the coefficients c_v become zero.

In one exemplary embodiment which is not illustrated, the second digital filters differ in the

integer number 2^{-L_v} which is used to multiply a discrete output value from a second digital filter in the feedback path. In this exemplary embodiment, the coefficients c_v in accordance with Equation (1) differ for every alternate digital filter, and that digital filter which results from the series connection of the second digital filters has a transfer function in accordance with Equation (1).

Figure 3 uses two diagrams to illustrate the effect of six different exemplary embodiments of time-domain equalizers according to the invention. To this end, the signal-to-noise ratio and the input of the decision-making circuit was simulated and an ADSL transmission system having a two-wire line with a length of 3 km and a diameter of 0.4 mm.

Only the influences from the time-domain equalizer were considered. The signal-to-noise ratio is plotted over the entire frequency band used for ADSL transmission. A respective curve profile is indicated for each of the six different time-domain equalizers, whose respective transfer functions are $H_1(z)$ to $H_6(z)$. The transfer functions $H_1(z)$ to $H_6(z)$ are as follows:

$$H_1(z)=1-z^{-1}$$

$$H_2(z)=(1-z^{-1})^2$$

$$H_3(z)=(1-z^{-1})^3$$

$$H_4(z)=\left(\frac{1-z^{-1}}{1-0.5\cdot z^{-1}}\right)$$

$$H_5(z)=\left(\frac{1-z^{-1}}{1-0.5\cdot z^{-1}}\right)^2$$

$$H_6(z)=\left(\frac{1-z^{-1}}{1-0.5\cdot z^{-1}}\right)^3$$

A curve profile without a time-domain equalizer and a curve profile having an optimized time-domain equalizer with 32 coefficients (32 taps) are shows for comparison. Both diagrams clearly show the improvement in the signal-to-noise ratio in the region of the lower frequencies. In the case of time-domain equalizers having a second, third or higher order digital filter, the signal-to-noise ratio differs from that of the optimized time-domain equalizer with 32 coefficients only by a few decibels above a frequency of about 300 kHz.

Patent Claims

1. A digital receiver for a signal (12) produced using discrete multitone modulation, which receiver has an analog/digital converter (2) to which the signal produced using discrete multitone modulation is supplied, and has a time-domain equalizer (3) connected downstream from the analog/digital converter, characterized in that the time-domain equalizer (3) has a digital filter with fixed coefficients (104, 204).

2. The digital receiver as claimed in claim 1, characterized in that the digital filter (100, 200) has integer values as fixed coefficients (104, 204).

3. The digital receiver as claimed in claim 1 or 2, characterized in that the digital filter (100, 200) has values which can be represented by shift operations as fixed coefficients (104, 204).

4. The digital receiver as claimed in one of the preceding claims, characterized in that the digital filter (100, 200) has a zero at 0 Hz.

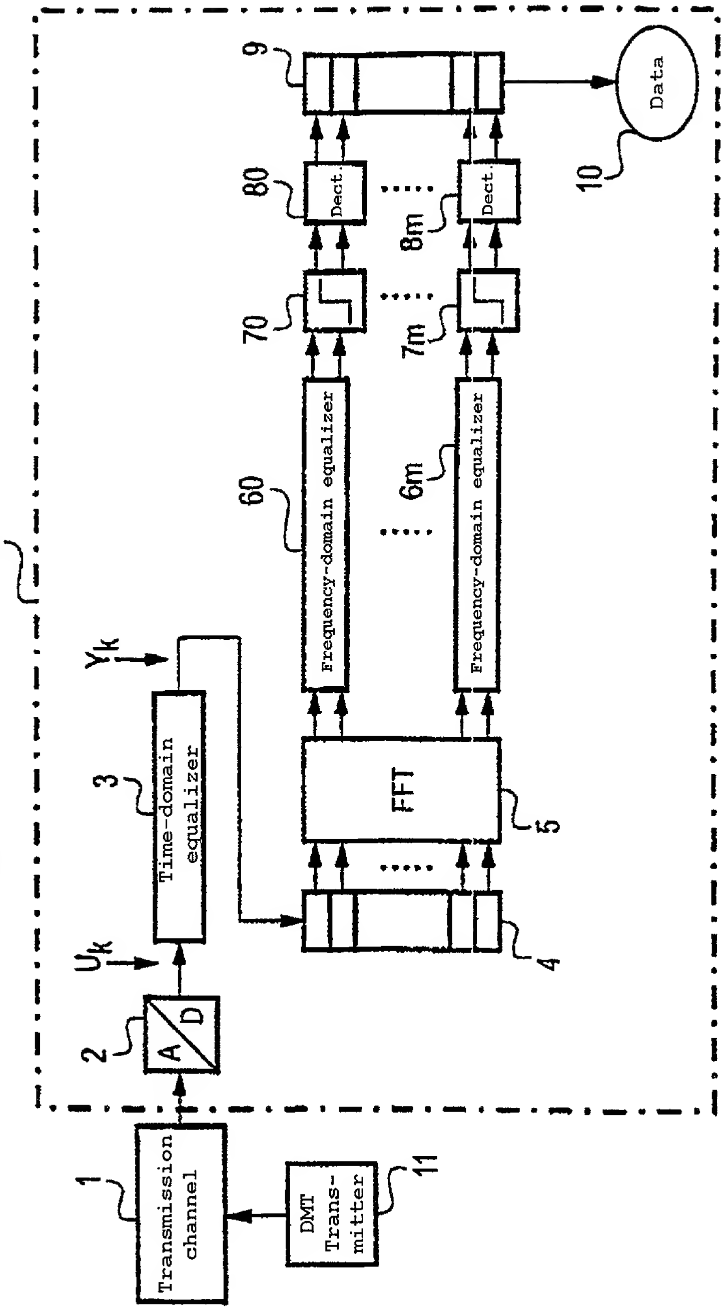
5. The digital receiver as claimed in one of the preceding claims, characterized in that the digital filter (100, 200) has a high-pass transfer function.

6. The digital receiver as claimed in one of the preceding claims, characterized in that

the digital filter has a series of circuits comprising a large number of first-order digital filters (100, 200).

7. The digital receiver as claimed in claim 6, characterized in that
each first-order digital filter has a state memory (102, 202), a shift register (104, 204), a digital subtraction circuit (101, 201) and a digital addition circuit (103, 203).

FIG 1


12
1
Transmission channel
11
DMT Transmitter
2
A D
U_k
3
Time-domain equalizer
Y_k
4
5
FFT
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6m
Frequency-domain equalizer
70
7m
80
Dect.
8m
Dect.
9
10
Data

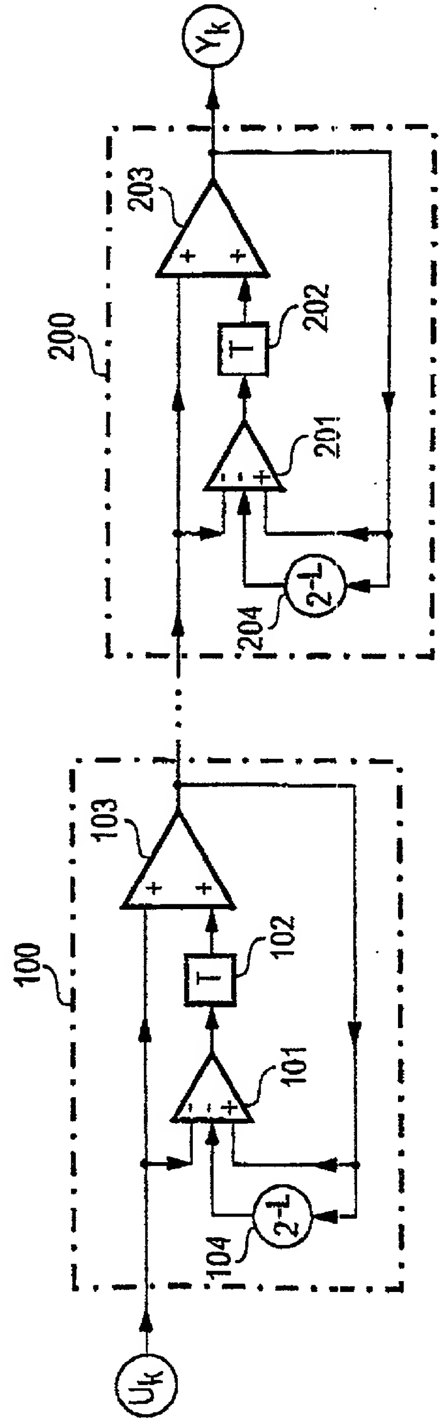


FIG 2

FIG 3A

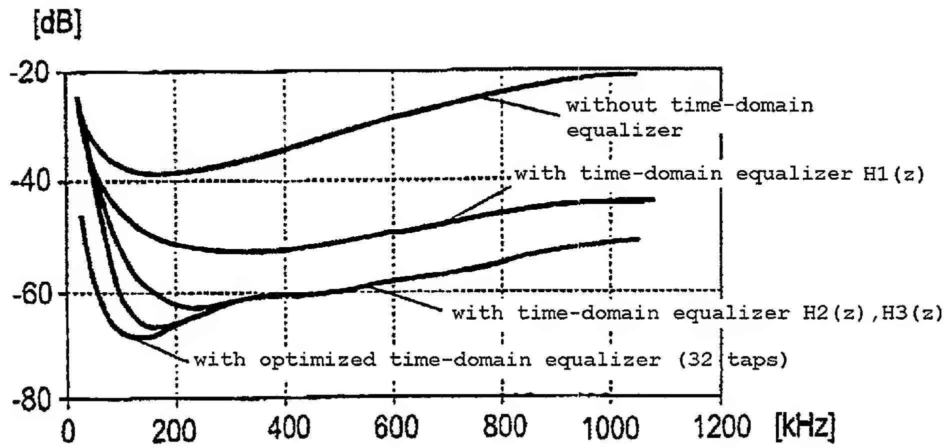
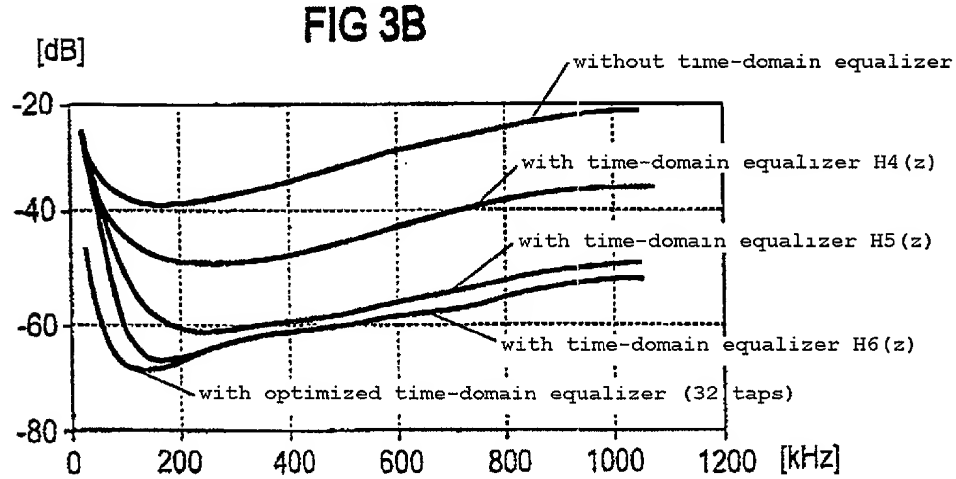

[dB]
-20
-40
-60
-80
0
200
400
600
800
1000
1200
[kHz]
without time-domain equalizer
with time-domain equalizer H1(z)
with time-domain equalizer H2(z),H3(z)
with optimized time-domain equalizer (32 taps)

FIG 3B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-40
-60
-80
0
200
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600
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1000
1200
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without time-domain equalizer
with time-domain equalizer H4(z)
with time-domain equalizer H5(z)
with time-domain equalizer H6(z)
with optimized time-domain equalizer (32 taps)

Attorney Docket Number: 12816-008001

DIGITAL RECEIVER FOR A SIGNAL PRODUCED USING DISCRETE MULTITONE MODULATION

FIELD OF INVENTION

The invention relates to a digital receiver for a signal produced using discrete multitone modulation

BACKGROUND

Discrete multitone modulation (DMT), also referred to as multicarrier modulation, is a modulation method which is particularly suitable for transmitting data via channels in which linear distortion occurs. In comparison to so-called single-carrier methods such as amplitude modulation, which has only one carrier frequency, discrete multitone modulation makes use of a large number of carrier frequencies. The amplitude and phase of each individual carrier frequency is modulated using quadrature amplitude modulation (QAM). This thus results in a large number of QAM-modulated signals. A specific number of bits may in each case be transmitted per carrier frequency. Discrete multitone modulation is used for digital audio broadcast DAB where it is referred to as OFDM (Orthogonal Frequency Division Multiplex) and for transmitting data via telephone lines, where it is referred to as ADSL (Asymmetric Digital Subscriber Line).

In ADSL, a DMT-modulated signal is used to transmit data from a switching center via a subscriber line to a subscriber with an analog connection. In this case, ETSI and ANSI Standards state that each carrier frequency has a bandwidth of approximately 4 kHz, and that at most up to 15 bits per second per Hz are transported. The actual number of bits per second per Hz may differ for each carrier frequency, thus allowing

the data rate and transmission spectrum to be matched to the transmission channel.

A DMT transmission system has a coder which combines the bits in a serial digital data signal which is intended to be transmitted, to form blocks. A specific number of bits in a block in each case have an associated complex number. A complex number is used to represent a carrier frequency $f_i = i/T$ where $i = 1, 2, \ldots, N/2$ in the discrete multitone modulation, with all the carrier frequencies f_i being distributed at equal intervals. T is the time duration of a block. Inverse Fourier transformation is used to transform the carrier frequencies represented by the complex numbers to the time domain, where they directly represent N samples of a DMT signal to be transmitted. In order to allow Inverse Fast Fourier Transformation (IFFT) to be used, a power of two is selected for N. This reduces the complexity for Inverse Fast Fourier Transformation.

After the Inverse Fast Fourier Transformation, a cyclic prefix is carried out, with the last M ($M < N$) of the samples being attached once again to the start of a block. A periodic signal is thus simulated for a receiver, once the transient process produced by a transmission channel has decayed after M samples corresponding to a time $T \cdot M/N$. The equalization complexity in the receiver can be greatly reduced by means of the cyclic prefix since, after demodulation in the receiver, all that is necessary is multiplication by the inverse of the transfer function of the transmission channel in order to compensate for the linear distortion in the transmission channel. This requires one complex or four real multiplications for each carrier frequency.

In ADSL, the physical transmission channel is a two-wire line (twin-core copper cable) in the telephone network. The two-wire line requires a long time for the transient process in comparison to the length of a block. On the other hand, any additional transmission capacity required as a result of the cyclic prefix is intended to be as low as possible.

A cyclic prefix of M = 32 is defined in ADSL for a block length of N = 512. However, the transient process on the two-wire line has not yet decayed after M = 32 values. Additional errors thus occur in the receiver, which cannot be compensated for by a frequency-domain equalizer.

Such additional errors can be reduced by using special signal processing measures in the receiver.

To this end, a time domain equalizer (TDEQ) is connected upstream of a demodulator. The time domain equalizer is in the form of a digital transversal filter, whose coefficients are adjustable. The object of the time domain equalizer is to shorten the transient process of the transmission channel. The design of such time-domain equalizers is described in Al-Dhahir, N., Cioffi, J.M., "Optimum Finite-Length Equalization for Multicarrier Transceivers", IEEE Trans.on Comm., Vol. 44, No. 1, Jan 1996. However, this has the disadvantage that the digital transversal filter used as the time-domain equalizer has a large number of coefficients, and the adaptation of the digital transversal filter is complex. A filter length of 20 to 40 coefficients means that approximately 50 to 100 million multiplication operations must be carried out per second. In addition, each coefficient must be

adjusted for adaptation of the digital transversal filter.

The technical problem on which the invention is based is thus to specify a digital receiver for a signal produced using discrete multitone modulation, which receiver has a time-domain equalizer which can be adapted more quickly and which carries out fewer multiplications per second.

SUMMARY

The invention relates to a digital receiver for a signal produced using discrete multitone modulation. The digital receiver has an analog/digital converter to which the signal produced using discrete multitone modulation is supplied, and has a time-domain equalizer connected downstream from the analog/digital converter. The time-domain equalizer in turn has a digital filter with fixed coefficients. The fixed coefficients of the digital filter as are required for adaptive digital filters and which require no effort for adaptation are advantageous in this case.

In one particularly preferred embodiment, the digital filter has integer values as fixed coefficients. It is particularly advantageous in this case that operations with integer values are less complex than operations with sliding-point values.

In a further particularly preferred embodiment, the digital filter has values which can be represented by shift operations as fixed coefficients. This advantageously allows multiplication operations to be replaced by shift operations, which are less complex.

In one preferred embodiment, the digital filter has a zero at 0 Hz, thus advantageously shortening the impulse response of the transmission system.

In a further preferred embodiment, the digital filter has a high-pass transfer function.

In one particularly preferred embodiment, the digital filter has a series circuit comprising a large number of first-order digital filters. The first-order filters can advantageously be produced very easily.

In a further particularly preferred embodiment, each first-order digital filter has a state memory, a shift register, a digital subtraction circuit and a digital addition circuit. The simple construction of each first-order filter is advantageous in this case, with no complex multiplication stages being required.

Further advantages, features and application options of the invention will become evident from the following description of exemplary embodiments in conjunction with the drawing, in which:

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a transmission path with a digital receiver for a signal produced using discrete multitone modulation;

Figure 2 shows an exemplary embodiment of a time-domain equalizer according to the invention; and

Figure 3 shows a diagram illustrating the effect of a time-domain equalizer according to the invention.

DETAILED DESCRIPTION

In the transmission path illustrated in Figure 1 and having a digital receiver **12**, a DMT transmitter **11** produces a signal modulated using discrete multitone modulation. The signal in this case has N/2 carrier frequencies f_1, which are produced by discrete multitone modulation. Each carrier frequency is in this case amplitude-modulated and phase-modulated using quadrature amplitude modulation. In the DMT transmitter **11**, the signal is provided with a cyclic prefix comprising M samples, and is converted by digital/analog conversion to an analog signal for transmission. The DMT transmitter **11** transmits the signal via a transmission channel **1** to the digital receiver **12**.

The transmission channel **1** is a channel which produces linear distortion. In the case of ADSL transmission paths, the transmission channel is a two-wire line. Such linear distortion produced by the transmission channel **1** is compensated for once again in the digital receiver **12** by means of equalizers which operate in the frequency domain.

In the digital receiver **12**, the signal is supplied to an analog/digital converter **2**, which converts it to a sequence of digital values u_k.

The sequence of digital values u_k is supplied to a time-domain equalizer **3**. The time-domain equalizer **3** is used to shorten the stabilization time of the DMT transmitter **11**, of the transmission channel **1** and of the time-domain equalizer **3** itself. If the stabilization time is greater than the cyclic prefix time duration, errors occur in the decision-maker

circuits **70** to **7m** in the digital receiver **12**. The time-domain equalizer **3** is intended to shorten the stabilization time without needing to produce any zeros in the frequency band which is used for transmission. To this end, the time-domain equalizer **3** has a digital filter with fixed coefficients and having the following transfer function ($z = u_k$):

$$H(z)=\prod_{v=1}^{n}\left(\frac{1-z^{-1}}{1-c_v\cdot z^{-1}}\right) \text{ where } c_v = \pm(1-2^{-L}) \quad (1)$$

This is the transfer function of a multistage digital filter which has fixed coefficients c_v and is produced by a series circuit comprising n second first-order digital filters with a transfer function

$$H_v(z)=\frac{1-z^{-1}}{1-c_v\cdot z^{-1}} \text{ where } c_v = \pm(1-2^{-L}) \quad (2)$$

The transfer function H(z) of the time-domain equalizer **3** has a zero at 0 Hz, and is thus the transfer function of a high-pass filter. This is the most effective way to shorten the stabilization process of the transmission channel.

The digital values produced by the time-domain equalizer **3** are supplied to a serial/parallel converter **4** which removes the cyclic preface and produces blocks which are supplied to a discrete Fast Fourier Transformation device **5**.

The discrete Fast Fourier Transformation device **5** converts the signals represented by the blocks from the time domain to the frequency domain. Each converted block at the output of the discrete Fast Fourier Transformation device **5** has N/2 complex numbers. Each

complex number represents a carrier frequency $f_i = i/T$ where i = 1, 2,..., N/2 for the discrete multitone modulation, with all the carrier frequencies f_i being distributed at equal intervals. T is the time duration of a block.

The discrete Fast Fourier Transformation device **5** is followed by a frequency-domain equalizer **60,..., 6m** for each carrier frequency $f_1, \ldots, f_{N/2}$ and this carries out the equalization process in the frequency domain. To this end, each complex number in the conversion block which represents one carrier frequency is multiplied by the inverse transfer function of the transmission channel **1**. This requires one complex multiplication operation, or four real multiplication operations.

Each frequency-domain equalizer **60,..., 6m** is followed by a respective decision-making circuit **70,..., 7m**, which produces a multistage value from the output signal from the frequency-domain equalizer **60,..., 6m**.

Each decision-making circuit **70,..., 7m** is in each case followed by a decoder circuit **80,..., 8m**, which produces a digital value from the multistage value.

The output signals from the decoder circuits **80,..., 8m** are supplied in parallel to a parallel/serial converter **9**, which is connected to a data sink **10**. The parallel/serial converter **9** supplies the data sink **10** with a serial stream of digital data, corresponding to the digital data from the DMT transmitter **11**.

Figure 2 shows an exemplary embodiment of a time-domain equalizer according to the invention.

The time-domain equalizer has a series circuit comprising n second first-order digital filters with a transmission function as in Equation (2). Figure 2 shows only two first-order digital filters **100** and **200**. Further second first-order digital filters are indicated by dots.

All the second first-order digital filters **100** and **200** are constructed in the same way. A discrete input value sequence is supplied to a first inverting input of a digital subtraction circuit **101** or **201**, respectively, and, in parallel, to a first non-inverting input of a digital addition circuit **103** or **203**, respectively. One output of the digital addition circuit **103** or **203**, respectively, is an output of the second first-order digital filter and is fed back in parallel form to a non-inverting input of the digital subtraction circuit and, via a shift register, to a second inverting input of the digital subtraction circuit **101** or **201**, respectively. The shift register **104** or **204**, respectively, multiplies a discrete output value by shifting to the right, bit-by-bit. In consequence, the discrete output value is multiplied by an integer number 2^{-L}. One output of the digital subtraction circuit **101** or **201**, respectively, is passed via a state memory **102** or **202**, respectively, to a second non-inverting input of the digital addition circuit **103** or **203**, respectively. The state memory **102** or **202**, respectively, produces a delay by one clock period of the clock which is used to clock the discrete input sequence.

If L = 0 is chosen, the second digital filters **100** and **200** are non-recursive. In this case, in accordance with Equation (2), the coefficients c_v become zero.

In one exemplary embodiment which is not illustrated, the second digital filters differ in the integer number 2^{-L_v} which is used to multiply a discrete output value from a second digital filter in the feedback path. In this exemplary embodiment, the coefficients c_v in accordance with Equation (1) differ for every alternate digital filter, and that digital filter which results from the series connection of the second digital filters has a transfer function in accordance with Equation (1).

Figure 3 uses two diagrams to illustrate the effect of six different exemplary embodiments of time-domain equalizers according to the invention. To this end, the signal-to-noise ratio and the input of the decision-making circuit was simulated on an ADSL transmission system having a two-wire line with a length of 3 km and a diameter of 0.4 mm.

Only the influences from the time-domain equalizer were considered. The signal-to-noise ratio is plotted over the entire frequency band used for ADSL transmission. A respective curve profile is indicated for each of the six different time-domain equalizers, whose respective transfer functions are $H_1(z)$ to $H_6(z)$. The transfer functions $H_1(z)$ to $H_6(z)$ are as follows:

$$H_1(z)=1-z^{-1}$$

$$H_2(z)=(1-z^{-1})^2$$

$$H_3(z)=(1-z^{-1})^3$$

$$H_4(z) = \left(\frac{1-z^{-1}}{1-0.5 \cdot z^{-1}} \right)$$

$$H_5(z) = \left(\frac{1-z^{-1}}{1-0.5 \cdot z^{-1}} \right)^2$$

$$H_6(z) = \left(\frac{1-z^{-1}}{1-0.5 \cdot z^{-1}} \right)^3$$

A curve profile without a time-domain equalizer and a curve profile having an optimized time-domain equalizer with 32 coefficients (32 taps) are shown for comparison. Both diagrams clearly show the improvement in the signal-to-noise ratio in the region of the lower frequencies. In the case of time-domain equalizers having a second, third or higher order digital filter, the signal-to-noise ratio differs from that of the optimized time-domain equalizer with 32 coefficients only by a few decibels above a frequency of about 300 kHz.

Having described the invention, and a preferred embodiment thereof, what is claimed as new, and secure by letters patent is:

CLAIMS PENDING AS OF MARCH 27, 2001

1. A digital receiver for receiving an input signal produced using discrete multitone modulation, said receiver comprising:

an analog/digital converter to which the input signal is supplied, and

a time-domain equalizer connected downstream from the analog/digital converter, the time-domain equalizer including a digital filter having fixed coefficients.

2. The digital receiver as claimed in claim **1**, wherein the fixed coefficients of the digital filter have integer values.

3. The digital receiver as claimed in claim **1**, wherein the fixed coefficients of the digital filter have values that can be represented by shift operations.

4. The digital receiver as claimed in claim **1**, wherein the digital filter has a zero at 0 Hz.

5. The digital receiver as claimed in claim **1**, wherein the digital filter is a high-pass filter.

6. The digital receiver as claimed in claim **1**, wherein the digital filter comprises a series of circuits, each of the circuits having a plurality of first-order digital filters.

7. The digital receiver as claimed in claim **6**, wherein each first-order digital filter comprises:

a state memory,

a shift register,

a subtraction circuit, and

an addition circuit.

ABSTRACT

A digital receiver for receiving DMT signals includes a time-domain equalizer that includes a digital filter having fixed coefficients.

Attorney Docket Number: 12816-008001

COPY OF SPECIFICATION SHOWING DIFFERENCES BETWEEN SUBSTITUTE SPECIFICATION AND SPECIFICATION AS FILED

~~Description~~

DIGITAL RECEIVER FOR A SIGNAL PRODUCED USING DISCRETE MULTITONE MODULATION

FIELD OF INVENTION

The invention relates to a digital receiver for a signal produced using discrete multitone modulation~~, as claimed in the precharacterizing clause of patent claim 1.~~

BACKGROUND

Discrete multitone modulation (DMT),~~--~~ also referred to as multicarrier modulation,~~--~~ is a modulation method which is particularly suitable for transmitting data via channels in which linear distortion occurs. In comparison to so-called single-carrier methods such as amplitude modulation, which has only one carrier frequency, discrete multitone modulation makes use of a large number of carrier frequencies. The amplitude and phase of each individual carrier frequency is modulated using quadrature amplitude modulation (QAM). This thus results in a large number of QAM-modulated signals. A specific number of bits may in each case be transmitted per carrier frequency. Discrete multitone modulation is used for digital audio broadcast DAB where it is referred to as OFDM (Orthogonal Frequency Division Multiplex) and for transmitting data via telephone lines, where it is referred to as ADSL (Asymmetric Digital Subscriber Line).

In ADSL, a DMT-modulated signal is used to transmit data from a switching center via a subscriber line to a subscriber with an analog connection. In this case, ETSI and ANSI Standards state that each carrier frequency has a bandwidth of approximately 4 kHz, and that at most up to 15 bits per second per Hz are transported. The actual number of bits per second per Hz may differ for each carrier frequency, thus allowing the

data rate and transmission spectrum to be matched to the transmission channel.

A DMT transmission system has a coder which combines the bits in a serial digital data signal which is intended to be transmitted, to form blocks. A specific number of bits in a block in each case have an associated complex number. A complex number is used to represent a carrier frequency $f_i = i/T$ where $i = 1, 2, \ldots, N/2$ in the discrete multitone modulation, with all the carrier frequencies f_i being distributed at equal intervals. T is the time duration of a block. Inverse Fourier transformation is used to transform the carrier frequencies represented by the complex numbers to the time domain, where they directly represent N samples of a DMT signal to be transmitted. In order to allow Inverse Fast Fourier Transformation (IFFT) to be used, a power of two is selected for N. This reduces the complexity for Inverse Fast Fourier Transformation.

After the Inverse Fast Fourier Transformation, a cyclic prefix is carried out, with the last M ($M < N$) of the samples being attached once again to the start of a block. A periodic signal is thus simulated for a receiver, once the transient process produced by a transmission channel has decayed after M samples corresponding to a time $T \cdot M/N$. The equalization complexity in the receiver can be greatly reduced by means of the cyclic prefix since, after demodulation in the receiver, all that is necessary is multiplication by the inverse of the transfer function of the transmission channel in order to compensate for the linear distortion in the transmission channel. This requires one complex or four real multiplications for each carrier frequency.

In ADSL, the physical transmission channel is a two-wire line (twin-core copper cable) in the telephone network. The two-wire line requires a long time for the transient process in comparison to the length of a block. On the other hand, any

additional transmission capacity required as a result of the cyclic prefix is intended to be as low as possible.

A cyclic prefix of M = 32 is defined in ADSL for a block length of N = 512. However, the transient process on the two-wire line has not yet decayed after M = 32 values. Additional errors thus occur in the receiver, which cannot be compensated for by a frequency-domain equalizer.

Such additional errors can be reduced by using special signal processing measures in the receiver.

To this end, a time domain equalizer (TDEQ) is connected upstream of a demodulator. The time domain equalizer is in the form of a digital transversal filter, whose coefficients are adjustable. The object of the time domain equalizer is to shorten the transient process of the transmission channel. The design of such time-domain equalizers is described in Al-Dhahir, N., Cioffi, J.M., "Optimum Finite-Length Equalization for Multicarrier Transceivers", IEEE Trans.on Comm., Vol. 44, No. 1, Jan 1996. However, this has the disadvantage that the digital transversal filter used as the time-domain equalizer has a large number of coefficients, and the adaptation of the digital transversal filter is complex. A filter length of 20 to 40 coefficients means that approximately 50 to 100 million multiplication operations must be carried out per second. In addition, each coefficient must be adjusted for adaptation of the digital transversal filter.

The technical problem on which the invention is based is thus to specify a digital receiver for a signal produced using discrete multitone modulation, which receiver has a time-domain equalizer which can be adapted more quickly and which carries out~~r~~ fewer multiplications per second.

SUMMARY

~~This problem is solved by a digital receiver for a signal produced using discrete multitone modulation and having the~~

~~features of patent claim 1. Advantageous refinements can be found in the respective dependent claims.~~

The invention relates to a digital receiver for a signal produced using discrete multitone modulation. The digital receiver has an analog/digital converter to which the signal produced using discrete multitone modulation is supplied, and has a time-domain equalizer connected downstream from the analog/digital converter. The time-domain equalizer in turn has a digital filter with fixed coefficients. The fixed coefficients of the digital filter as are required for adaptive digital filters and which require no effort for adaptation are advantageous in this case.

In one particularly preferred embodiment, the digital filter has integer values as fixed coefficients. It is particularly advantageous in this case that operations with integer values are less complex than operations with sliding-point values.

In a further particularly preferred embodiment, the digital filter has values which can be represented by shift operations as fixed coefficients. This advantageously allows multiplication operations to be replaced by shift operations, which are less complex.

In one preferred embodiment, the digital filter has a zero at 0 Hz, thus advantageously shortening the impulse response of the transmission system.

In a further preferred embodiment, the digital filter has a high-pass transfer function.

In one particularly preferred embodiment, the digital filter has a series circuit comprising a large number of first-order digital filters. The first-order filters can advantageously be produced very easily.

In a further particularly preferred embodiment, each first-order digital filter has a state memory, a shift register, a digital subtraction circuit and a digital addition circuit. The simple construction of each first-order filter is advantageous in this case, with no complex multiplication stages being required.

Further advantages, features and application options of the invention will become evident from the following description of exemplary embodiments in conjunction with the drawing, in which:

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a transmission path with a digital receiver for a signal produced using discrete multitone modulation; ~~and~~

Figure 2 shows an exemplary embodiment of a time-domain equalizer according to the invention; and

Figure 3 shows a diagram illustrating the effect of a time-domain equalizer according to the invention.

DETAILED DESCRIPTION

In the transmission path illustrated in Figure 1 and having a digital receiver **12**, a DMT transmitter **11** produces a signal modulated using discrete multitone modulation. The signal in this case has N/2 carrier frequencies f_1, which are produced by discrete multitone modulation. Each carrier frequency is in this case amplitude-modulated and phase-modulated using quadrature amplitude modulation. In the DMT transmitter **11**, the signal is provided with a cyclic prefix comprising M samples, and is converted by digital/analog conversion to an analog signal for transmission. The DMT transmitter **11** transmits the signal via a transmission channel **1** to the digital receiver **12**.

The transmission channel **1** is a channel which produces linear distortion. In the case of ADSL transmission paths, the transmission channel is a two-wire line. Such linear distortion produced by the transmission channel **1** is compensated for once again in the digital receiver **12** by means of equalizers which operate in the frequency domain.

In the digital receiver **12**, the signal is supplied to an analog/digital converter **2**, which converts it to a sequence of digital values u_k.

The sequence of digital values u_k is supplied to a time-domain equalizer **3**. The time-domain equalizer **3** is used to shorten the stabilization time of the DMT transmitter **11**, of the transmission channel **1** and of the time-domain equalizer **3** itself. If the stabilization time is greater than the cyclic prefix time duration, errors occur in the decision-maker circuits **70** to **7~~n~~m** in the digital receiver **12.** The time-domain equalizer **3** is intended to shorten the stabilization time without needing to produce any zeros in the frequency band which is used for transmission. To this end, the time-domain equalizer **3** has a digital filter with fixed coefficients and having the following transfer function ($z = u_k$):

$$H(z)=\prod_{v=1}^{n}\left(\frac{1-z^{-1}}{1-c_v\cdot z^{-1}}\right) \text{ where } c_v = \pm(1-2^{-L}) \quad (1)$$

This is the transfer function of a multistage digital filter which has fixed coefficients c_v and is produced by a series circuit comprising n second first-order digital filters with a transfer function

$$H_v(z)=\frac{1-z^{-1}}{1-c_v\cdot z^{-1}} \text{ where } c_v = \pm(1-2^{-L}) \cancel{.} (2)$$

The transfer function H(z) of the time-domain equalizer **3** has a zero at 0 Hz, and is thus the transfer function of a

high-pass filter. This is the most effective way to shorten the stabilization process of the transmission channel.

The digital values produced by the time-domain equalizer **3** are supplied to a serial/parallel converter **4** which removes the cyclic preface and produces blocks which are supplied to a discrete Fast Fourier Transformation device **5**.

The discrete Fast Fourier Transformation device **5** converts the signals represented by the blocks from the time domain to the frequency domain. Each converted block at the output of the discrete Fast Fourier Transformation device **5** has N/2 complex numbers. Each complex number represents a carrier frequency f_i = i/T where i = 1, 2, ..., N/2 for the discrete multitone modulation, with all the carrier frequencies f_i being distributed at equal intervals. T is the time duration of a block.

The discrete Fast Fourier Transformation device **5** is followed by a frequency-domain equalizer **60**, ..., **6m** for each carrier frequency f_1, ..., $f_{N/2}$ and this carries out the equalization process in the frequency domain. To this end, each complex number in the conversion block which represents one carrier frequency is multiplied by the inverse transfer function of the transmission channel **1**. This requires one complex multiplication operation, or four real multiplication operations.

Each frequency-domain equalizer **60**, ..., **6m** is followed by a respective decision-making circuit **70**, ..., **7m**, which produces a multistage value from the output signal from the frequency-domain equalizer **60**, ..., **6m**.

Each decision-making circuit **70**, ..., **7m** is in each case followed by a decoder circuit **80**, ..., **8m**, which produces a digital value from the multistage value.

The output signals from the decoder circuits **80**, ..., **8m** are supplied in parallel to a parallel/serial converter **9**, which is connected to a data sink **10**. The parallel/serial converter **9** supplies the data sink **10** with a serial stream of digital data, corresponding to the digital data from the DMT transmitter **11**.

Figure 2 shows an exemplary embodiment of a time-domain equalizer according to the invention.

The time-domain equalizer has a series circuit comprising n second first-order digital filters with a transmission function as in Equation (2). Figure 2 shows only two first-order digital filters **100** and **200**. Further second first-order digital filters are indicated by dots.

All the second first-order digital filters **100** and **200** are constructed in the same way. A discrete input value sequence is supplied to a first inverting input of a digital subtraction circuit **101** or **201**, respectively, and, in parallel, to a first non-inverting input of a digital addition circuit **103** or **203**, respectively. One output of the digital addition circuit **103** or **203**, respectively, is an output of the second first-order digital filter and is fed back in parallel form to a non-inverting input of the digital subtraction circuit and, via a shift register, to a second inverting input of the digital subtraction circuit **101** or **201**, respectively. The shift register **104** or **204**, respectively, multiplies a discrete output value by shifting to the right, bit-by-bit. In consequence, the discrete output value is multiplied by an integer number 2^{-L}. One output of the digital subtraction circuit **101** or **201**, respectively, is passed via a state memory **102** or **202**, respectively, to a second non-inverting input of the digital addition circuit **103** or **203**, respectively. The state memory **102** or **202**, respectively, produces a delay by one clock period of the clock which is used to clock the discrete input sequence.

If L = 0 is chosen, the second digital filters **100** and **200** are non-recursive. In this case, in accordance with Equation (2), the coefficients c_v become zero.

In one exemplary embodiment which is not illustrated, the second digital filters differ in the integer number 2^{-L_v} which is used to multiply a discrete output value from a second digital filter in the feedback path. In this exemplary embodiment, the coefficients c_v in accordance with Equation (1) differ for every alternate digital filter, and that digital filter which results from the series connection of the second digital filters has a transfer function in accordance with Equation (1).

Figure 3 uses two diagrams to illustrate the effect of six different exemplary embodiments of time-domain equalizers according to the invention. To this end, the signal-to-noise ratio and the input of the decision-making circuit was simulated ~~and~~on an ADSL transmission system having a two-wire line with a length of 3 km and a diameter of 0.4 mm.

Only the influences from the time-domain equalizer were considered. The signal-to-noise ratio is plotted over the entire frequency band used for ADSL transmission. A respective curve profile is indicated for each of the six different time-domain equalizers, whose respective transfer functions are $H_1(z)$ to $H_6(z)$. The transfer functions $H_1(z)$ to $H_6(z)$ are as follows:

$$H_1(z)=1-z^{-1}$$

$$H_2(z)=(1-z^{-1})^2$$

$$H_3(z)=(1-z^{-1})^3$$

$$H_4(z)=\left(\frac{1-z^{-1}}{1-0.5\cdot z^{-1}}\right)$$

$$H_5(z)=\left(\frac{1-z^{-1}}{1-0.5\cdot z^{-1}}\right)^2$$

$$H_6(z)=\left(\frac{1-z^{-1}}{1-0.5\cdot z^{-1}}\right)^3$$

A curve profile without a time-domain equalizer and a curve profile having an optimized time-domain equalizer with 32 coefficients (32 taps) are shown~~s~~ for comparison. Both diagrams clearly show the improvement in the signal-to-noise ratio in the region of the lower frequencies. In the case of time-domain equalizers having a second, third or higher order digital filter, the signal-to-noise ratio differs from that of the optimized time-domain equalizer with 32 coefficients only by a few decibels above a frequency of about 300 kHz.

<u>Having described the invention, and a preferred embodiment thereof, what is claimed as new, and secure by letters patent is:</u>

DIFFERENCES BETWEEN CLAIMS PENDING AND CLAIMS ORIGINALLY FILED

1. A digital receiver for receiving an input signal ~~(12)~~ produced using discrete multitone modulation, ~~which~~ said receiver comprising:

~~has~~ an analog/digital converter ~~(2)~~ to which the input signal ~~produced using discrete multitone modulation~~ is supplied, and ~~has~~

a time-domain equalizer ~~(3)~~ connected downstream from the analog/digital converter, ~~characterized in that~~ the time-domain equalizer ~~(3)~~ including~~has~~ a digital filter ~~with~~having fixed coefficients ~~(104, 204)~~.

2. The digital receiver as claimed in claim **1**, ~~characterized in that~~wherein the fixed coefficients of the digital filter ~~(100, 200)~~ ~~has~~have integer values ~~as fixed coefficients (104, 204)~~.

3. The digital receiver as claimed in claim **1** ~~or **2**~~, ~~characterized in that~~wherein the fixed coefficients of the digital filter ~~(100, 200)~~ ~~has~~ have values that~~which~~ can be represented by shift operations ~~as fixed coefficients (104, 204)~~.

4. The digital receiver as claimed in ~~one of the preceding~~ claim~~s~~ 1, wherein~~characterized in that~~ the digital filter ~~(100, 200)~~ has a zero at 0 Hz.

5. The digital receiver as claimed in ~~one of the preceding~~ claim~~s~~ 1, ~~characterized in that~~wherein the digital filter ~~(100, 200)~~ is~~has~~ a high-pass ~~transfer function~~filter.

6. The digital receiver as claimed in ~~one of the preceding~~ claim~~s~~ 1, wherein~~characterized in that~~ the digital filter comprises~~has~~ a series of circuits, each of the circuits

having ~~comprising~~ a plurality~~large number~~ of first-order digital filters~~ (100, 200)~~.

7. The digital receiver as claimed in claim **6**, ~~characterized in that~~wherein each first-order digital filter ~~has~~comprises:

a state memory ~~(102, 202)~~,

a shift register ~~(104, 204)~~,

a ~~digital~~ subtraction circuit, ~~(101, 201)~~ and

an ~~digital~~ addition circuit ~~(103, 203)~~.

Attorney's Docket No.: 12816-008001
Client's Ref. No.: S0751 SB/fis

COMBINED DECLARATION AND POWER OF ATTORNEY

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled DIGITAL RECEIVER FOR A SIGNAL PRODUCED USING DISCRETE MULTITONE MODULATION, the specification of which:

[] is attached hereto.
[] was filed on _ as Application Serial No. _ and was amended on _______________.
[X] was described and claimed in PCT International Application No. DE/99/02752 filed on September 1, 1999 and as amended under PCT Article 19 on _______________.

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose all information I know to be material to patentability in accordance with Title 37, Code of Federal Regulations, §1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, §119 of any foreign application(s) for patent or inventor's certificate or of any PCT international application(s) designating at least one country other than the United States of America listed below and have also identified below any foreign application for patent or inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America filed by me on the same subject matter having a filing date before that of the application(s) of which priority is claimed:

Country	Application No.	Filing Date	Priority Claimed
Germany	198 44 460.5	September 28, 1998	[X] Yes [] No

I hereby appoint the following attorneys and/or agents to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith:

Frank R. Occhiuti, Reg. No. 35,206   Faustino A. Lichauco, Reg. No. 41,942

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patents issued thereon.

Attorney's Docket No.: 12816-008001
Client's Ref. No.: S0751 SB/fis

Combined Declaration and Power of Attorney

1-00

Full Name of Inventor: HEINRICH SCHENK

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